

# New Generation Stellar Physics: Asteroseismology & Virtual Observatory

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Received 30 May 2005, accepted 11 Nov 2005

Published online later

**Key words** standards – astronomical databases: miscellaneous – stars: oscillations – stars: methods: statistical – stars: interiors

In the last years we have witnessed a dramatic change in the research infrastructures: Advances in communication networks, computational resources and data storage devices are fostering new and more efficient science. In this new scenario, the Virtual Observatory (VO) is the framework where a new methodology for astronomical research is being built. This poster shows the natural connection between Asteroseismology and VO. We describe the current status of a project developed by the Spanish Virtual Observatory in which, for the first time, asteroseismic models together with visualization tools for asteroseismology are managed within VO.

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## 1 Introduction

The twentieth century has provided an important qualitative and quantitative leap in the development of science and technology. The perfect symbiosis between the two has opened new horizons in the knowledge of nature: from the study of the fundamental components of matter, through life sciences, to better understand of the origin and evolution of the Universe and its components, like galaxies, stars, planets, to name a few.

In the last decades we have witnessed a significant progress of Stellar Physics, largely due to the development of its great laboratory: the stellar seismology (also known as asteroseismology). Today, several space missions have been designed to study the interior of stars and search for extra-solar planets like MOST (Matthews et al. 1998), CoRoT (Baglin et al. 2003), or Kepler (Gilliland et al. 2010) and some others are in preparation like PLATO (Catala 2009). Besides this, several precision instruments are being used for the first time for asteroseismology (CRIRES, UVES, FOCES, FEROS, HARPS) and others are currently in phase of development: NAHUAL (Martín et al. 2005), GIANO (Oliva et al. 2006), CARMENES (Quirrenbach et al. 2009), etc.

Moreover, one of the great revolutions in data transmission is undoubtedly the emergence of the Internet and its boundless possibilities. Day after day, new Internet-based technologies such as Web, Web 2.0, social networks, etc. come up with new useful tools. In astrophysics, this break-

through has its own name: the Virtual Observatory<sup>1</sup> (VO). Today, this tool allows us to handle hundreds of terabytes in a single click, and access to thousands of astronomy databases interlinked through a single web portal.

We present a new generation tool for stellar physics: the fusion of Virtual Observatory technologies with asteroseismology. The result is a tool conceived to easily handle observations and models in the framework of the large research programs like the above mentioned space missions. We seek to offer to the community a tool from which users have access to very different models without building interfaces, easily find models representative of the studied stars, and even compare online global and shell physical variables of a selection of models.

## 2 The project details

The official name of the project (the name of the tool is to be defined) is "Development of a VO-tool for asteroseismic models". It is currently under development within the Spanish Virtual Observatory Project<sup>2</sup> (SVO).

The staff is composed by four researchers: A. Moya, A. García Hernández, E. Solano (project manager) and J.C. Suárez (principal investigator), and one technician (C. Rodrigo), from two institutions: the Instituto de Astrofísica de Andalucía (IAA-CSIC), and the Centro de Astrobiología (CAB-INTA-CSIC).

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<sup>1</sup> <http://ivoa.net/>

<sup>2</sup> <http://svo.cab.inta-csic.es/>

Presently, around  $5 \cdot 10^5$  asteroseismic models are implemented in the tool. These have been computed using three different codes:

- The evolutionary code CESAM (Morel 1997) which provides the equilibrium models.
- The FILOU code (Suárez 2002; Suárez, Goupil & Morel 2006; Suárez & Goupil 2008) which provides adiabatic oscillations corrected for the effect of rotation.
- The GraCo code (Moya et al. 2004; Moya & Garrido 2008a).

This VO service is flexible enough to incorporate, in the future, other collections coming from different codes and/or databases that might be of interest for other groups.

We have implemented in the tool the following technical services

- A S3 server for each code<sup>3</sup>.
- A web application using he S3 services to find, select and analyze data<sup>4</sup>.
- The first *data model* for asteroseismic data<sup>5</sup>.

The data model mentioned above consists in 17 stellar global properties (e.g. effective temperature, surface gravity, luminosity, etc.), 44 star shell variables (e.g. density, pressure, temperature, etc.), and 35 seismic properties (e.g. frequency ranges, fundamental radial mode, large separation, etc.). These correspond to input criteria that can be queried simultaneously to the tool database service (see Fig. 1) in order to find all the models in the databases selected by the user.

Figure 2 illustrates the results yield by the tool, given some inputs parameters queried by the user. This include information on the number of *valid* results, i.e. the number of models matching the input criteria, the common values (databases might be very heterogenous, so common physical parameters provide an idea of which variables are simultaneously shared by all the models), and the list of valid models. This list contains some useful variables, like mass, metallicity, effective temperature, surface gravity, etc. Models can be sorted by any of these variables. Moreover, it is possible to visualize and/or dowload each of the selected models together with the model track they belong to<sup>6</sup>.

For all the valid models yield by the tool, it is possible to make diagrams with global and shell variables. An example of a plot with global variables is the HR diagram shown in Fig. 3. Plots are flexible and allow modification of scales (e.g. for zooming and/or using a logarithmic scale) and variables. Moreover, interactive shell variable plots are also implemented. These consist in diagrams of in-shell variables (i.e. variables varying with the model shell, for instance with the stellar radius), in which the user can compare the behavior of such variables for different selected models (see e.g. Fig. 4).

<sup>3</sup> <http://svo.cab.inta-csic.es/theory/sisms3>

<sup>4</sup> <http://svo.cab.inta-csic.es/theory/sisms3/>

<sup>5</sup> <http://svo.cab.inta-csic.es/theory/sisms3/concepts.php>

<sup>6</sup> Databases are constructed by including model evolutionary tracks. For each of the models of the tracks, the oscillation spectrum is also provided.

\* Take into account that some combinations of values could correspond to no result

CESAM2k evolutionary code + GraCo oscillation code

Structure search parameters		Sismology search parameters	
(?) Teff	[ ] - [ ] (K)	(?) F0	[ ] - [ ] (mHz)
(?) Lum	[ ] - [ ] (Lsun)	(?) F1	[ ] - [ ] (mHz)
(?) Log(g)	[ ] - [ ] (g/cm <sup>3</sup> )	(?) F0F1	[ ] - [ ] (mHz)
(?) Density	[ ] - [ ] (g/cm <sup>3</sup> )	(?) ΔV	[ ] - [ ] (mHz)
(?) Age	[ ] - [ ] (Myr)	(?) δ(v)	[ ] - [ ] (mHz)
(?) [Fe/H]	[ ] - [ ]	(?) [v]	[ ] - [ ] (mHz)
(?) Z	[ ] - [ ]	(?) [I]	[ ] - [ ]
(?) Hcent	[ ] - [ ]	(?) Sta.	all modes
(?) R_*	[ ] - [ ] (Rsun)	(?) V <sub>z</sub> z	[ ] - [ ] (mHz)
(?) Mass	[ ] - [ ] (Msun)		
(?) Vrot	[ ] - [ ] cm/s		
(?) Wrot	[ ] - [ ] rad/s		
(?) Trot	[ ] - [ ] sec		
(?) α <sub>MLT</sub>	[ ] - [ ]		
(?) Over.	[ ] - [ ]		

Search | Reset

References:  
 • CESAM2k evolutionary code  
 • GraCo oscillation code

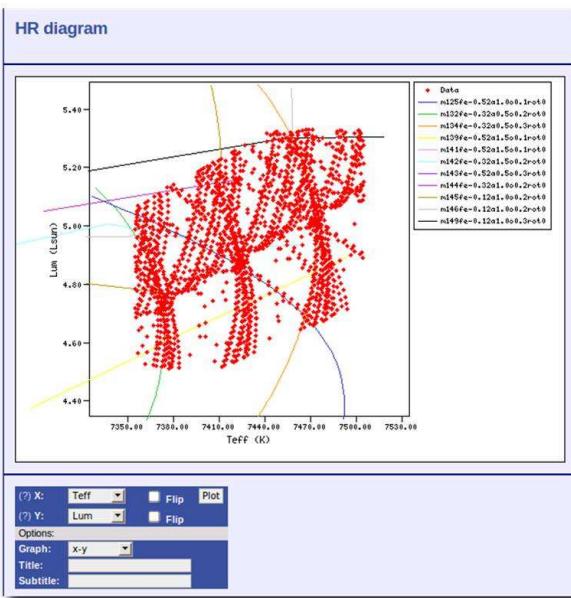
**Fig. 1** Snapshot of the web user interface in which the user provides input parameters for search queries. Global stellar parameters together with equilibrium model physical parameters (left column), and pulsation variables (right column). Prior to this interface, the user has previously selected the model databases in which the tool will send the user queries.

CESAM2k evolutionary code + GraCo oscillation code																
68 results have been found for your search criteria. You can click on column titles to sort results by that field																
Common values																
Mark	Files	Track	Teff	Lum	Log(g)	Density	Age	R_*	Mass	F0	F1	F0F1	ΔV	Δ(I0)V	Δv	Δ(I0)v
			0.0800	0.0200	0.6912	0	0.5000	0.2000								
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4997.5000	3.1613	3.7354	0.1318	4058.9000	2.3700	1.2502	101.9600	134.6100	0.7574	38.7420	1.5678	-23.7700	5.6460
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4992.4000	3.1177	3.7300	0.1300	4055.9000	2.3855	1.2502	101.2600	133.7600	0.7573	38.5320	1.5667	-24.4040	5.7216
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4989.6000	3.1195	3.7367	0.1285	4053.9000	2.3945	1.2502	100.6600	132.9600	0.7570	38.3330	1.5656	-25.1440	5.8316
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4990.1000	3.2531	3.7378	0.1273	4054.9000	2.4024	1.2502	100.2000	132.3600	0.7570	38.1410	1.5626	-25.9500	5.9016
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4995.8000	3.2404	3.7315	0.1262	4056.9000	2.4090	1.2502	99.9410	131.8600	0.7570	37.9660	1.5463	-26.7800	6.0092
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4981.5000	4.5406	3.6328	0.0730	4864.7000	2.8918	1.2502	76.2460	100.8600	0.7560	37.9650	1.2784	-14.9500	20.7370
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4986.5000	4.5408	3.6305	0.0576	4862.9000	1.8661	1.2502	72.9513	86.7400	0.7560	37.9650	1.1830	-22.2500	22.2500
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4987.5000	4.5408	3.6305	0.0576	4862.9000	1.8661	1.2502	72.9513	86.7400	0.7560	37.9650	1.1830	-22.2500	22.2500
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4756.0000	4.4511	3.5459	0.0579	4695.1000	1.2124	1.2502	65.0200	88.3880	0.7564	25.6240	1.2485	-10.7800	5.6250
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4695.0000	4.4282	3.5252	0.0538	4631.3000	1.3986	1.2502	61.4910	85.0220	0.7239	26.5450	1.1541	-19.7600	28.2930
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4617.4000	4.3599	3.5964	0.0505	4625.9000	1.2966	1.2502	58.2370	82.3000	0.7098	24.9030	1.1262	-17.0000	30.0980
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4489.0000	4.2770	3.4699	0.0477	4938.5000	3.3313	1.2502	55.3560	78.9360	0.6934	24.9070	1.1410	-16.7100	32.9770
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4431.0000	4.0703	3.4648	0.0455	4935.7000	3.4245	1.2502	50.8330	76.4100	0.6644	23.5330	1.1542	-16.3400	35.1790
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4363.8000	3.9567	3.4548	0.0423	4975.0000	3.4685	1.2502	48.7610	75.0610	0.6496	23.2560	1.0936	-15.8700	36.4150
<input type="checkbox"/>	cesam2k_graco	m125000.050.50.2100	4363.8000	3.9568	3.4548	0.0423	4975.0000	3.4685	1.2502	48.7610	75.0610	0.6496	23.2560	1.0936	-147.0000	37.8580

**Fig. 2** Snapshot with an illustration of the outputs shown by the tool with the models matching all the input criteria simultaneously. On top, a table summarizes the common parameters/variables to all the resulting models, and the number of *valid* models, i.e. those matching all the user-defined input criteria simultaneously. VOtables and complete models can be downloaded, in complete tracks or individually by selecting them in the results table. From this interface, models can be marked to be analyzed with visualization tools.

To summarize, the main characteristics of this VO tool are:

- Efficiency. The VO tool queries multiple model databases in seconds.
- Collections of models are handled easily and with user-friendly web interfaces.
- The only software required is a web browser with Javascript.
- Tables, figures, and model collections are fully downloadable.



**Fig. 3** Snapshot with an illustration of a Herzprung-Russel diagram of the models matching all the input criteria simultaneously. Dots correspond to the effective temperature and luminosity of all the valid models, and lines represent some of the selected evolutionary tracks.

- Designed for the easy and rapid comparison of very different and heterogeneous models.
- Visualization tools are available
- The tool offers new scientific potential.

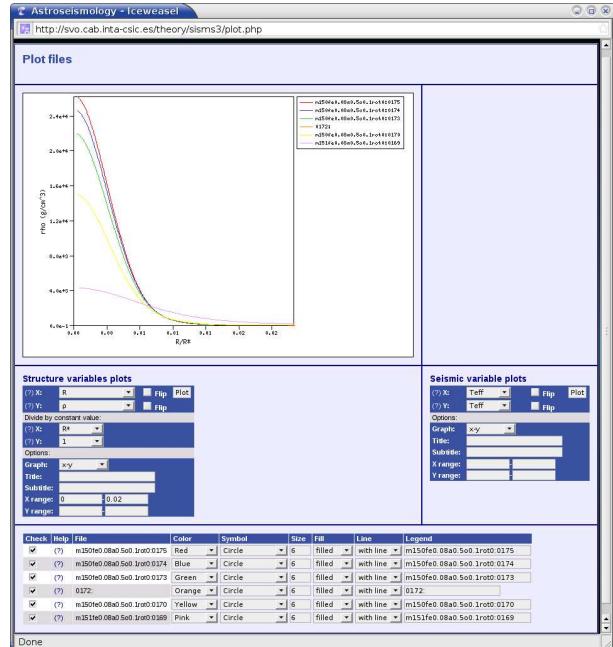
The possibility of managing a huge amount of models, their online comparison and visualization, opens new possibilities in the research itself. For instance, the user of this tool will be able to search for general properties in very different and heterogeneous databases, to make statistics, or simply focus in the science, instead of spending a significant amount of time building interfaces, dealing with formats, writing codes for plotting results, etc. An example of application is the recently comparison (Moya et al. 2008b) of oscillation codes undertaken within the scientific exploitation of the asteroseismic space mission *CoRoT*.

### 3 Future prospects

The present VO tool will be *see the web light* during this year. This will be done in a scientific publication with peer review. To do so, we are currently preparing a scientific case, which is mainly based on oscillation mode statistics for intermediate-mass, main-sequence stars (see, for instance, García-Hernández et al. 2009, Poretti et al. 2009).

Then, once the tool is published, we will initiate a contact round with research groups interested in adapting their model databases to VO.

From the point of view of technical implementation, it is envisaged to link directly observational input parameters



**Fig. 4** Snapshot with an illustration of a shell-variable type diagram of the models matching all the input criteria simultaneously. In particular, this diagram depicts the variation of the density (in c.g.s.) as a function of the radial distance normalized to the stellar radius.

from other VO tools. This will empower the tool for the use with large scientific programs producing lots of data, like space missions.

In what regards the modeling, we are currently studying the possibility of linking this tool with GRID computing-based technology, and the use of genetic algorithms.

**Acknowledgements.** JCS acknowledges support from the "Instituto de Astrofísica de Andalucía (CSIC)" by an "Excellence Project post-doctoral fellowship" financed by the Spanish "Consejería de Innovación, Ciencia y Empresa de la Junta de Andalucía" under project "FQM4156-2008". JCS also acknowledges support by the Spanish "Plan Nacional del Espacio" under project ESP2007-65480-C02-01.

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